AUDIO FREQUENCY INDUCTION LOOP SYSTEM (AFILS) FOR ORIENTATION AND MOBILITY

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***Abstract* — This article investigates the use of audio loop for mobility and orientation to help individuals with vision loss navigate streets, parks, and other public venues. The proposed Audio Frequency Induction Loop System for Orientation and Mobility (AFILS-OM) is a comprehensive technology to assist visually impaired individuals when crossing a street at a street crossing or intersection. It can also be used in public venues such as airports. AFILS-OM is composed of a communication loop (C-Loop) used for speech communication and a guide loop (G-Loop) to guide through street crossings or park trails using a cane equipped with a telecoil (T-Cane). The audio loop is achieved with electric wire or wires configured in a loop which can be concealed in concrete, pavement, building walls, under carpet, or inside ceilings. The loop replicates in form of electromagnetic waves any input signal to the loop driver to which it is attached. These signals can be picked up with a telecoil and used for communication or guide. The nature and reliability of the electromagnetic signals are clearly demonstrated in our laboratory experiments and computer simulations. This paper presents the feasibility concept of AFILS-OM and the supporting results from measurements and computer simulations.**

Keywords: Visual Impairment, Hearing Loop, Orientation and Mobility, Blindness, Street crossing.

I. INTRODUCTION

This Blind and low vision individuals face major challenges when traveling in unfamiliar environments because of the lack of preview, knowledge of the environment, and access to

reliable orientation information. As a result, visually impaired people are less engaged in travel and activities outside their homes or restricted community. They are frequently less engaged in society which affects their productivity, employment, leisure and self-maintenance activities (Marston & Golledge, 2003) [1] and (Walker & Lindsay, 2006) [2]. Therefore, to support their ability to freely travel and interact with their general environment, visually impaired individuals rely on assistance from sighted guides, white canes, or dog guides; but also on the use of technology.

Advances in assistive technologies for mobility and orientation are increasingly helping those with visual impairment in their daily activities to facilitate mobility, independence, and safety (Bahadira, Koncara, & Kalaoglub) [3] and (Cheng, 2016) [4]. Developers of assistive technologies for wayfinding have made several electronic devices such as personal GPS units, ultrasonic mobility devices, and Bluetooth mobility and orientation systems to enhance the traveling experience of persons who are blind (Shioyama & Shorif, 2004) [5]. Most of these devices are meant to be used in conjunction with other mobility aids. An example of such mobility aids is the Laser Cane (Benjamin, 1973) [6] which uses invisible laser beams to detect obstacles, drop offs, and similar hazards in the surroundings. Once the cane detects the obstacle or drop off using the laser beams, it produces a vibration or an audio signal specific to the nature of the obstacle making it suitable for persons who are blind and persons who are deaf blind. The laser cane is often supplemented with ultrasonic obstacle detection eye glasses. The glasses are like spectacles and vibrate near a potential hazard at head and chest height. The vibration gradually increases in frequency as the distance to the obstacle decreases, down to a distance of 0.7 meters (2 feet) when the vibration becomes continuous. Since, other types of cane have been developed such as the one described by Rizzo (Rizzo et al., 2017) [7].

A more promising technology is the OrCam. According to the manufacturer website (OrCam, 2018) [8], “OrCam harnesses the power of artificial vision to compensate for lost visual abilities. OrCam is a sensor that sees what is in front of you, understands what information you seek and provides it to you through a bone-conduction earpiece. OrCam understands what you want on its own, whether it’s to read, find an item, catch a bus or cross the road. Faces and places are recognized continuously. OrCam will tell you when it sees a face or a place it recognizes, without you having to do anything”. Similar technology, such as Argus II is a retinal prosthesis. Surgically attached array of electrodes to the eye retinal receive signals from a pair of glasses with a video camera worn by the patient. The camera captures video footage and transmits the images as series of

electrical pulses to the eye that the brain then perceives as visual images. The result is not a normal vision per se. But patients who were unable to see anything before using the Argus II are able to detect shapes and pick up contrast between light and dark.

Many other technologies are being investigated as described by Bengisu's review of assistive products in Turkey (Bengisu, 2010) [9] and the electronic bracelet proposed by Bhatlawande (Bhatlawande, 2014) [10]. Universities and companies like IBM, Microsoft, Toyota (La Monica, 2016) [11], and Baidu are working on technologies ranging from smart glasses to better computer-vision software that could one day serve as digital eyes for the more than ¼ billion visually impaired people worldwide. Also technologies destined to non-humans will greatly benefit the visually impaired. For example the technology for Internet of Things (IoT) or the artificial intelligence developed for self-driving cars could be some day repurposed as assistive technologies. More importantly the blind will be able to use the self-driving cars to get around.

Perhaps with the exception of the claim from the OrCam manufacturer, most of these devices are not capable to specifically identify a crosswalk, or potentially figure out the state of the traffic signals. The technology proposed herein is using guidelines from Orientation and Mobility (O&M) expert to provide a simple and cost effective way to assist visually impaired pedestrians navigate traffic intersections. These guidelines were proposed by Dona Sauerburger (Sauerburger, 2005) [12] and were meant for O&M specialists and their students to overcome the challenges of street crossings. The author identified risks based on the type of intersection and proposed guidelines for crossing. These are a) Strategies for intersections with traffic signals, b) Strategies for crossing streets with stop signs, c) Strategies at uncontrolled crossings.

After several decades into the technology revolution, the cane remains one of the most widely used assistive tools for visually impaired people to navigate the world. This is because most of the devices require advance Research and Development (R&D) and are destine to a minority group that often does not have the means to purchase these expensive devices. Most of the technologies proposed are years away to serve a greater number of the visually impaired population. The technology proposed in this paper is aimed to serve the general population of visually impaired and has the potential to complement individual devices such as wearable cameras and eye glasses.

II. DESCRIPTION OF AFILS-OM

An Audio Frequency Induction Loop System (AFILS) is more commonly known as a "hearing loop". A hearing loop is a wire that circles an

area and is connected to a sound system as shown (Williams Sound, 2015) [13] in Fig. 1. The wire is usually laid flush with floors and walls and may even be placed in the baseboards or underneath the carpet. It can also be installed in the ceiling. For outdoor application, the wire can be laid in concrete or in buried tubes. The two ends of the wire is then connected to a loop driver creating a closed loop that can transmit through electromagnetic waves any signal from a source connected to the loop driver. The input signal into the source port of the loop driver is often sound or speech. The electromagnetic waves are then picked up by the telecoil in the hearing aid, cochlear implant, or other type of electromagnetic wave receivers including landline and cell phones with telecoil.

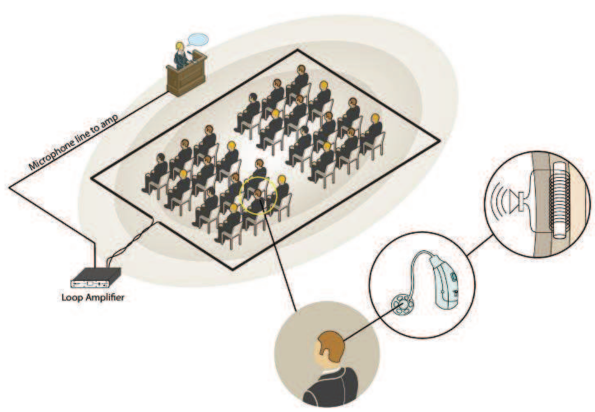

Fig. 1. Hearing loop configuration

A telecoil, shown in Fig. 2, is a small copper coil with a metal core that is used in loop receivers, phones, most hearing aids, and is built into cochlear implant processors. Telecoils are also known as t-coils and were originally used in telephone handset. All landline and some cell phones are designed by law to be used with a telecoil. When used with a loop, the telecoil transforms the alternating magnetic flux from the loop into voltage which is amplified to drive a speaker thus replicating the sound or speech input to the loop driver.

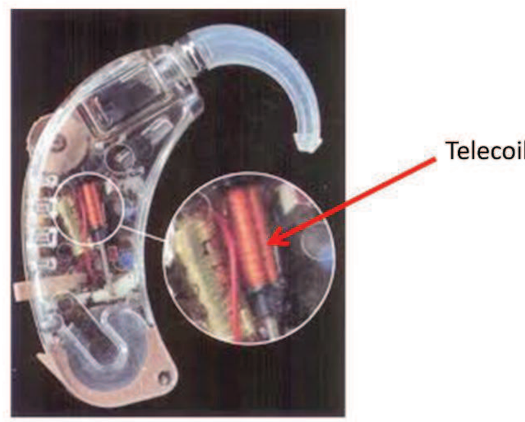

Fig. 2. Hearing aid with telecoil

The Audio Frequency Induction Loop System described above is a major component of the proposed technology. This technology is to assist visually impaired pedestrians in public venues, street crossings, or intersection (Li, Jeon, and Nam, 2015) [14]. AFILS-OM is composed of a communication loop or C-Loop that provides information in the form of audio signal or speech directly into the users loop receiver, a guide loop or G-Loop that guides the user between virtual rails, and a cane equipped with a telecoil or T-Cane to detect the G-Loop and provides vibration signal to keep the visually impaired pedestrian within the travel

path. AFILS-OM can be used to deliver targeted information to a person with visual impairment in public places such airports, street sidewalks or crossings, shopping malls etc. It can also be used for hard of hearing and visually impaired individuals provided they have hearing aids with telecoil.

The most practical application of AFILS-OM is its use at street crossings or intersections. Street crossing in general is very complex even at intersections with traffic signals. Right-turn-on-red, multiple lanes streets, quieter cars, and other features make it a challenge for every pedestrian and especially for elderly people; children; and people with cognitive, mobility, and/or hearing disabilities in addition to visual impairment. The major concern is often how to make these intersections safe for all users. This concern continue to be addressed by researchers with expertise ranging from orientation and mobility training to smart intersections.

Most cities are generally poorly equipped to deal with blind pedestrians but new technologies introduced in recent years try to remedy that situation. Some cities started to equip traffic signals with audio versions of green and red lights but also beepers to guide visually impaired pedestrians through the intersection (Harkey et al., 2009) [15]. The objective of AFILS-OM for street crossing and intersections is to provide these instructions in real time directly to the visually impaired pedestrian via the telecoil of a hearing aids, smart phone, or loop receiver as opposed to open air speaker broadcasting. Used in combination with T-Cane and G-loop, AFILS-OM can guide the user through a system of virtual rails while crossing streets.

A. C-Loop

Communication Loop (C-Loop) shown in Fig. 3 can be installed in the concrete as previously stated and the drivers/amplifiers mounted in the traffic light control enclosure. The main purpose of this type of audio loop will be to communicate information to the user and thus is referred to as C-Loop. Traffic lights status or other information about the intersection such as accident or congestion can be fed to the AFILS-OM drivers /amplifiers continuously.

Furthermore, for multiple lanes streets, additional audio loops can be used halfway across each segment of the intersection, to provide more locational information. A visually impaired pedestrian or elderly person within the loop field will receive the intersection status information in form of speech or audio signal through hearing aids, loop receivers, or cell phone with telecoil.

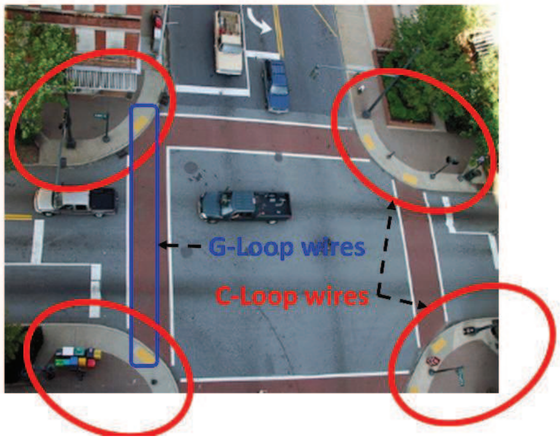

Fig. 3. Typical AFILS-OM layout at an intersection

B. *T-Cane*

The T-Cane concept shown in Fig. 4 represents a normal white Cane with an embedded telecoil. The telecoil is designed so that its axis remains parallel to the surface of the street all the time and consequently to the loop wire. The output of the telecoil is monitored and used to generate vibrations in the cane to alert the T-Cane user that the cane is over a loop wire. Additionally, when used with the G-Loop, the T-Cane is able to provide the user with information on the location of the virtual lane created by the G-Loop. This allows the visually impaired pedestrian to remain on the path of travel delimited by the invisible G-Loop wires.

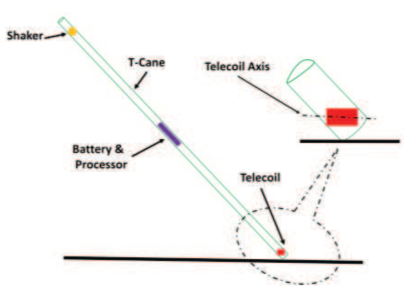

Fig. 4. White cane with telecoil (T-Cane)

C. *G-Loop*

The G-Loop shown in Fig. 5 is a component of the Assistive Pedestrian Audio Loops (AFILS-OM) system and is aimed to guide the visually impaired pedestrians along the travel path. The guide loop is setup similar to the C-Loop except that it has two loops offset by 10 cm. The wires carry single tone signals at different frequencies. The frequencies are selected outside the audible frequency band in order to avoid interference when a C-Loop is present. The outer loop of the G-Loop is used to point the user toward the inside of the loop and also to help identify the entrance of the virtual lane created by the G-Loop. The G-Loop can be installed at any street crossing and intersection with or without traffic light provided there is power available to help visually impaired pedestrian cross along the crossing path. It can be installed along trails or sidewalks, in public area such as shopping malls or airport to help guide users with visual impairment.

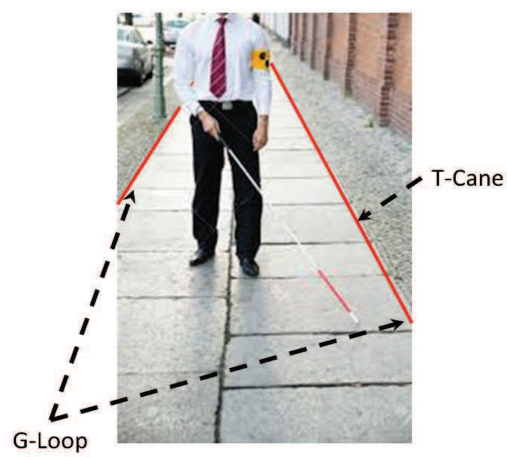

Fig. 5. Guide Loop on a sidewalk (G-Loop)

III. AFILS-OM SIMULATION

Audio loops are generally installed indoor to transmit audio signals via electromagnetic waves. Their outdoor installations are often limited to creating electromagnetic waves to sense the presence of vehicles at intersections. The analysis in this section is carried out to better understand the various factors involved in the performance of an audio loop when installed outdoor. Computer simulation and experimental measurements are used to assess the implementation of AFILS-OM. Given the intense computer power requirement of the electromagnetic field computation, a reduced size audio loop is used. Electromagnetic similitude can then be used to extrapolate the results to real word scenario. First electro-magnetostatic approach is used to investigate the effect of reinforcing steel bars, light posts, and traffic signal controller enclosures on the magnetic field. Then a transient analysis validated with experimental measurement is conducted to establish baseline values for the loop receivers.

A. *Magnetostatic Analysis of a Current Loop*

The objective of this section is to validate the ANSYS finite element model with numerical calculations and known result in literature. For the current loop of Fig. 6, the magnetic field (Ulaby and Ravaioli, 2014) [16].

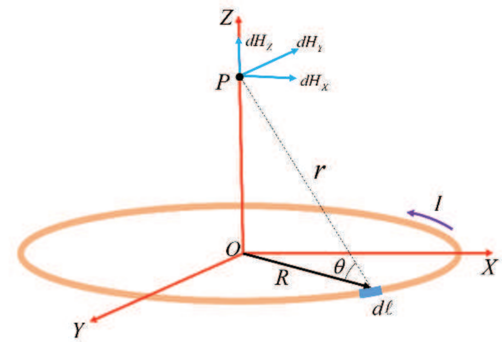

Fig. 6. Current loop and Magnetic field at point P

along the $z-axis$ is given by Eq. (1). The current loop is modelled in ANSYS Maxwell with $R = 0.5m$ and $I = 1A$. The component of the magnetic field along the $z-axis$ from the simulation is plotted against the magnetic field calculated with Eq. (1) and shown in Fig. 7. The results show a perfect agreement between the finite element and the numerical models values.

$$B_z = \frac{H_z}{\mu_0} = \frac{\mu_0 I R^2}{2(z^2 + R^2)^{3/2}} \quad (1)$$

where $\mu_0 = 4\pi e^{-7}(T.m / A)$ is the free field permeability, I is a constant current.

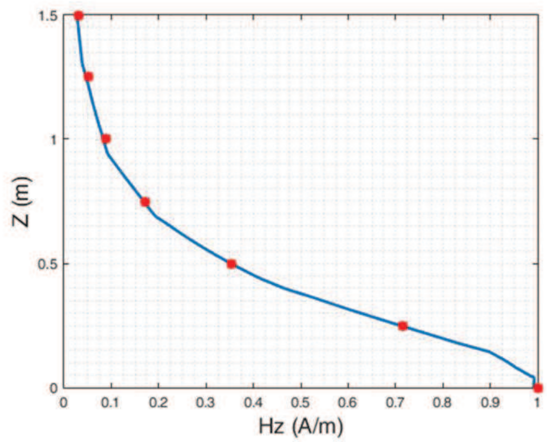

Fig. 7. Magnetic field of the loop along the (Red: numeric, Blue: ANSYS).

The same finite element model is used to assess the magnetic field uniformity inside the loop and the degree of spillover of the magnetic flux outside the loop in a plane parallel to the loop plane at $Z=1.5m$. We also defined pilot points in the plane of the loop wire at $Z=0$ in order to compare the values of their magnetic field from ANSYS and numerical values calculated using a computer program.

The results are presented in Table 1. The values in the table and the plots of Figs. 8 and 9 indicate that the magnetic field is optimum inside the loop and quickly drops at about half of its maximum value at a distance one loop diameter away from the center.

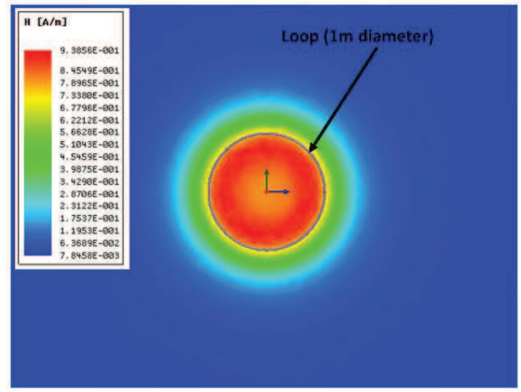

Fig. 8. Magnetic field of the loop in a plane $Z=1.5m$.

The third simulation is to assess the effect of the surrounding on the performance of the loop. Especially the effect of the reinforcing steel bars in the concrete and the traffic light posts. Thus, concrete with reinforcing steel bars and a traffic light post is added to the model. The permeability of the concrete is close to that of a free field so it is not included in the model. The loop is placed $13mm$ in the concrete and the magnetic field at $Z=1.5m$ above the street level is plotted in Figs. 10 and 11.

The result clearly shows a reduction in the filed strength caused by the reinforcing steel bars. Also the magnetic field is not symmetric anymore due to the presence of the steel traffic light post.

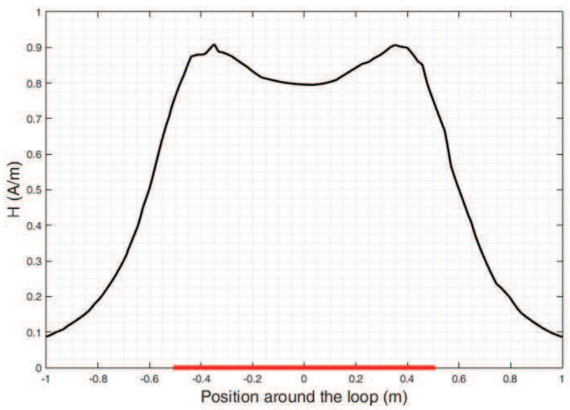

Fig. 9. Magnetic field of the loop at $z = 1.5m$ along the $x - axis$.

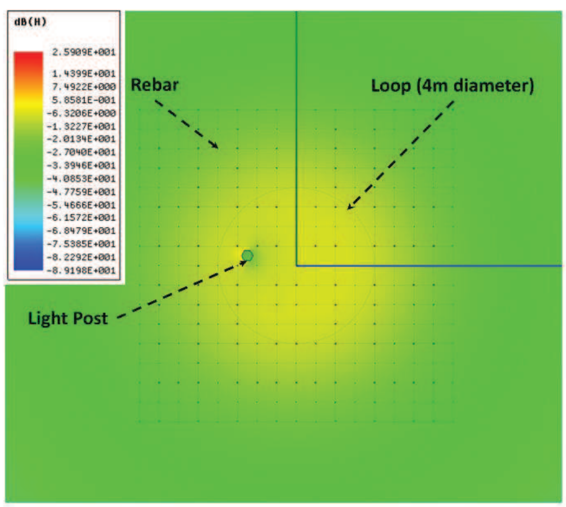

Fig. 10. Magnetic field in a plane at $Z = 1.5m$ for a loop embedded in concrete

B. *Transient Analysis of a Current Loop*

An Audio Frequency Induction Loop System (AFILS) primary function is to transmit audio frequency via electromagnetic waves. Therefore, it is better analysed using its transient characteristics. In this section we will focus on the computer simulation and experimental analysis of the response of a current loop. The ideal case is to analyse the response of the loop to input signal at the frequencies recommended by the International Electrotechnichal Commission (IEC) for the certification of a Hearing Loop, however we feel that the investigation of the response of the loop to a test input signal of sine wave will suffice. In general, there is a reasonable correlation between the response of a system to a standard test input and the system's ability to perform under normal operating conditions (Lennart, 1999) [17]. From design point of view, using a standard input of $1kHz$ sine wave will help compare several competing designs. Therefore we will use a sine wave $i = I\sin(2\pi Ft)$ as input current into the loop of both the ANSYS model and the experimental loop of Fig. 12. The input signal is set as $I = 1A$ and $F = 1000Hz$ in the computer model which correspond to $I = 0.707A(rms)$ in the experimental audio loop. The computer model is setup as previously described except here a transient analysis is carry out for $0.25ms$. The magnetic field values are saved for the pilot points shown in Fig. 13. For the experiment, the loop is setup in an open air field to reduce interference and electromagnetic background noise. The objective is to create a free field permeability condition in and around the loop. First the magnetic background noise is measured using

a Contacta Field Strength Meter (FSM). Next, a Contacta audio test signal generator is used to supply a sine wave signal to a Univox DLS-50 loop driver. The current in the loop is measured with digital multimeter and adjusted to $I = 0.707A(rms)$. Finally, the magnetic field strength is measured at the pilot points. These points are located in a plane at $Z = 0.1m$ above the loop. The results in Table 1 shows an agreement between the finite element model at time $t = 0.25ms$ and the experimental measurements. The magnetic field strength distribution due to the variable input current from the computer model is shown at time $t = 0.25ms$ in Fig. 14.

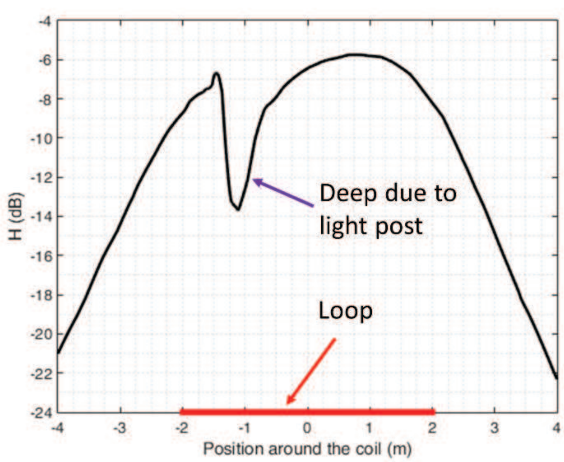

Fig. 11. Magnetic field at $z = 1.5m$ along $x - axis$ $z = 1.5m$ for a loop embedded in concrete.

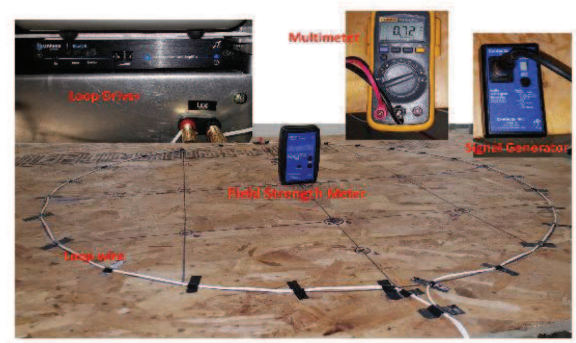

Fig. 12. Experimental setup.

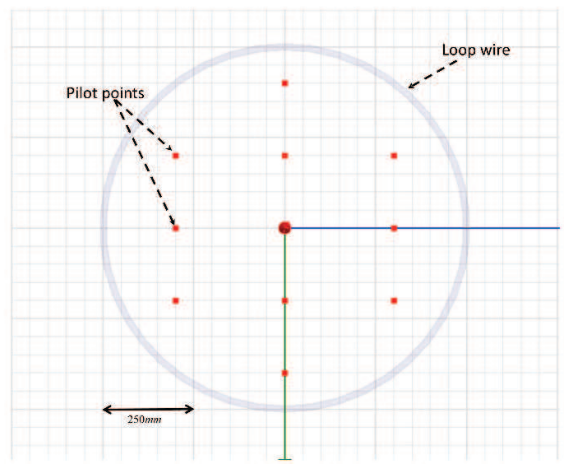

Fig. 13. Pilot points

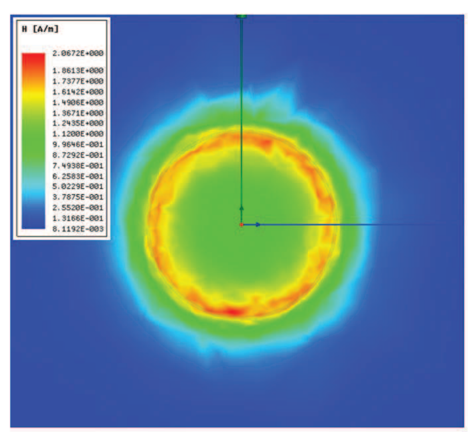

Fig. 14. Magnetic field of the loop in a plane $z = 0.1m$.

TABLE I
COMPARISON OF MAGNETIC FIELD AT PILOT POINTS

Pilot Point	X(m)	Y(m)	Z(m)	H_{exp} *(dB)*	H_{ansys} *(dB)*
1	0.4	0	0.1	5.5	5.6
2	0.2	0	0.1	5.2	5.6
3	0	0	0.1	4.3	4.4
4	-0.2	0	0.1	5.0	5.1
5	-0.4	0	0.1	5.3	5.5
6	0.2	0.3	0.1	5.3	5.3
7	0	0.3	0.1	4.9	5.1
8	-0.2	0.3	0.1	5.5	5.6
9	0.2	-0.3	0.1	5.7	6.0
10	0	-0.3	0.1	5.0	5.2
11	-0.2	-0.3	0.1	5.5	5.8

IV. AFILS-OM IMPLEMENTATION

The successful physical implementation of AFILS-OM relies on the engineering and technology necessary for the installation and servicing of the loops (Kim *et al*. 2016) [18]. However, to have a durable impact, AFILS-OM deployment must incorporate potential government regulations and training of the general and visually impaired population. For the installation of the loops, C-loop or G-Loop, the most important factor is the physical configuration of the area inside the loop wires. For example a $300 loop driver can cover up to $112m^2$ area or a loop of $6m$ radius. The same loop driver can cover up to $183mm$ long and $0.6m$ wide walkway. Additionally the loop driver can be powered by solar panels with backup battery for rural area applications or crossing without traffic signal or power. Thus, based on the proposed applications: street intersections or crossings, park trails, and public areas such as shopping malls, the cost of AFILS-OM installation and deployment is quite reasonable.

The engineering data presented above shows that the output electromagnetic signal is attenuated due to the presence of reinforcing steel bars in the concrete or metal posts. This will lead to the selection of a larger loop driver in such application to compensate for the attenuation. Nevertheless, even with a slightly more expensive loop driver, the implementation of AFILS-OM is more cost effective then alternative technology proposed by other researchers.

V. CONCLUSION

An Audio Frequency Induction Loop System for Orientation and Mobility (AFILS-OM) to help visually impaired pedestrians has been proposed in this paper. Computer simulation and experimental analysis have been used to assess the implementation of AFILS-OM in outdoor setting and with the presence of concrete reinforcing steel bars and traffic and light posts. The AFILS-OM system consist of C-Loops, G-Loops, and a T-Canes that can be installed and used at street crossings or intersections, in public venues such as malls and city halls, and on park trails. At an intersection application, the AFILS-OM system can provide real time traffic and tricolor traffic lights status in form of speech or audio signal. The system can also provide a countdown of the time left to start or to finish a crossing. More importantly, all this helpful information can be clearly transmitted to the pedestrian into an ear-bud as opposed to current open air loudspeaker broadcasting system used at intersections. Additionally, the system will help the pedestrian stay within the designated crossing path using the virtual walls created by the G-Loop. AFILS-OM is a simple and cost effective approach to allow individuals with visually impairment enjoy park trails and safely use street sidewalks. The presented analysis and implementation can be used as a starting point for the real world implementation of the Audio Frequency Induction Loop System for Orientation and Mobility (AFILS-OM). Future work will include clinical trial of the system in a controlled environment.

REFERENCES

[1] Marston, J. R. and Golledge, R. G. (2003). The hidden demand for participation in activities and travel by persons who are visually impaired, Journal of Visual Impairment & Blindness, 97, 475–488.

[2] Walker, B. N. and Lindsay, J. (2006). Navigation performance with a virtual auditory display: Effects of beacon sound, capture radius, and practice. Human Factors, 48, 265–278.

[3] Bahadira, K., Koncara, V., Kalaoglub, F. (2012). Wearable obstacle detection system fully integrated to textile structures for visually impaired people. Sensors and Actuators, A179, 297-311

[4] Cheng, P-H. (2016). Wearable ultrasonic guiding device with white cane for the visually impaired: A preliminary verisimilitude experiment. Journal of assistive technology, 28(3), 127-136.

[5] Shioyama, T. and Shorif, M. (2004). Detection of pedestrian crossings with projective invariants from image data, Meas. Sci. Technol. 15, 2400–2405.

[6] Benjamin, J. (1973). A Laser Cane for the Blind. Proc. San Diego Biomedical Symposium.

[7] Rizzo, J-R, Conti, K, Thomas, T., Hudson, T., Emerson, R. W., and Kim, D. S. (2017). A new primary tool for visually impaired: A white cane-adaptive mobility device hybrid. Journal of assistive technology.

[8] OrCam (2016). Retrieved http://www.orcam.com/

[9] Bengisu, M. (2010). Assistive Technologies for Visually Impaired Individuals in Turkey. Journal of assistive technology, 22, 163-171.

[10] Bhatlawande et al. (2014). Electronic Bracelet and Vision-Enabled Waist-Belt for Mobility of Visually Impaired People. Journal of assistive technology, 26, 186-195.

[11] La Monica, P.R. (2016). This company helps blind people see. Retrieved from http://money.cnn.com/2016/02/29/investing/second-sight-blindness-vice/

[12] Sauerburger, D. (2005). Street Crossings: Analyzing Risks, Developing Strategies, and Making Decisions, Journal of Visual Impairment & Blindness, 99(10).

[13] Williams Sound (Helping People Hear). (2015). Design Guide, Induction Loop Systems. TECH 007B (2015)

[14] Li, Y., Jeon, W. R., Nam, and C. S. (2015). Navigation by vibration: Effects of vibrotactile feedback on a navigation task. International Journal of Industrial Ergonomics, 46, 76-84.

[15] Harkey, D. L., et al. (2009). Accessible Pedestrian Signals: A Guide to Best Practices, National Cooperative Highway Research Program, Contractor's Guide for NCHRP Project 3-62A.

[16] Ulaby, F. T. and Ravaioli, U. (2014). Fundamentals of Applied Electromagnetics, Pearson Education, Inc.

[17] Lennart, L. (1999). System Identification: Theory for the User (2nd Edition). Prentice Hall PTR, Upper Saddle River, NJ.

[18] Kim, K., Han, S., Park, Ja., Park, Jo. (2016). The interaction experiences of visually impaired people with assistive technology: A case study of smartphones. International Journal of Industrial Ergonomics, 55, 22-33